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Quantifying the potential impact of energy efficiency and low carbon policies for China

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Executive Summary

In 2006, China set for the first time a binding target for energy efficiency by requiring a 20% reduction in energy intensity per unit of GDP from 2005 to 2010 and began initiating sector-specific policies and measures to support further reductions in energy and CO_2 intensity through 2015 and 2020. While data on achievements of some industrial energy-saving programs has been reported, there are limited estimates on the potential impact of many existing and potential new policies and no consistent methodology for defining baselines and calculating savings potential, making policy prioritization and evaluation difficult for policymakers. This paper presents a prospective analysis of policy-specific energy savings and emissions reductions through 2030 for key existing policies and new policies likely to be implemented in the buildings, industry and transport sectors.

This paper evaluates building policies that include: more stringent building codes, building energy labelling programs, district heating, metering and controls, and retrofits; industry policies that include efficiency improvements for 7 energy-intensive industries, technology switching for cement, iron and steel and aluminum industries, and use of alternative fuels for cement industry; and transport policies that include fuel economy standards, hybrid and electric vehicles, bus rapid transit and car-trip diversion strategies. LBNL's China Energy End Use Bottom-up Model was used to evaluate transport and industrial policies along with Excel-based spreadsheet model to evaluate building policies. Although simplifying assumptions and model parameter uncertainties could affect total savings potential estimates for specific policies, this paper help guide policy prioritization in China by identifying and highlighting the policies with the highest magnitude of savings potential such as building codes, fuel economy standards and industrial efficiency policies.

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Quantifying the potential impact of energy efficiency and low carbon policies for China

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1. Introduction

In 2006, China set for the first time a binding target for energy efficiency by requiring a 20% reduction in energy intensity per unit of GDP during the 11th Five-Year Plan (FYP) from 2005 to 2010. In support of these goals, sector-specific energy efficiency policies and programs including the Top-1000 Program for industry and cross-sector Ten Key Projects were initiated. A mid-term evaluation of the 11th FYP policies by LBNL found that most policies were on track to meet or exceed their 11th FYP savings targets and in 2011, the Chinese government reported total reduction of 19.1% in energy intensity per unit of GDP over the 11th FYP period (Price et al. 2011). The Top-1000 program which set energy savings targets for China's largest 1000 energy-consuming enterprises in nine key industrial sub-sectors, for instance, was reported to have achieved total energy savings of 150 Million tons of coal equivalent (4.4 EJ) from 2006 to 2010 (NDRC 2011). The Ten Key Projects included a wide range of potential energy-savings areas with industry and buildings as two major components, but the total savings achieved has not been reported. More recently, China has continued to set binding targets for 16% and 17% energy and carbon intensity per unit of GDP reductions, respectively, for its 12th FYP period from 2011 to 2015. The 12th FYP continues to focus on improving energy efficiency in buildings, industry and transport along with improving energy transformation, energy supply and storage and energy research and development.

With growing focus on China's energy use and emission mitigation potential – from both inside and outside of China – the past decade has seen the development of a range of Chinese outlook models by Chinese and international institutions. These outlook models and their accompanying projections of China's future energy use and CO_2 emissions help inform policymakers by illustrating potential development paths for China under different macroeconomic conditions and the adoption of different combinations of policies. However, a recent review of several key Chinese energy and CO_2 emissions outlook models revealed key differences in modelling methodology and scenarios as well as varying assumptions about GDP growth and efficiency improvements that in turn affect the modelling results (Zheng et al. 2010). Some models, such as those used by China's Energy Research Institute (ERI 2009) and the University of Sussex's Tyndall Centre for Climate Change (Wang and Watson 2009), incorporate a top-down modelling approach while others including McKinsey (McKinsey & Company 2009), the International Energy Agency (IEA 2010) World Energy Outlook, and Lawrence Berkeley National Laboratory (LBNL) China Energy Group's China End-Use model follow a bottom-up modelling approach with physical drivers. The LBNL China End-Use model, for example, based its assumptions mostly on physical drivers for energy activities for the end use and technologies instead of economic drivers such as price, and GDP growth rate. In terms of major scenarios generated by the models, almost all studies had at least one baseline or reference scenario and an alternative mitigation scenario. Although there was a general clustering in total energy consumption of different sets of scenarios in the five studies reviewed, there was a notable difference in the shape of the energy and emissions curve between LBNL's scenarios and others. Zheng et al. 2010 showed that while China's primary energy consumption will not plateau until the 2040s, CO_2 emissions could peak in the late 2020s to early 2030s under the two efficiency scenarios. The difference arises because the two LBNL efficiency scenarios were modeled from a highly disaggregated end-use level for the major sectors and used physical drivers, and assumes a number of saturation effects will take place for drivers including the slowdown of urbanization, low population growth, change in exports to high value added products, and saturation of most appliances, floor area per resident and per employee, and infrastructure construction[1]. While the LBNL study presented two possible development paths with continued and aggressive efficiency improvements across all sectors, it did not evaluate the specific energy and emission reduction impacts of different sectoral policies.

The development of bottom-up energy end-use models represents one possible methodology for evaluating the impact of existing policies being implemented as well as new policies being considered in China, an increasingly important task given the recent binding targets. While data on achievements of past industrial energy-saving programs such as the Top 1000 program is available in China, there are limited estimates of the potential future impact of many other policies and programs and no consistent methodology for defining baselines and calculating official savings, making policy prioritization and evaluation difficult for policymakers. To provide insight into how existing and potentially new policies and programs can contribute to China's future goals, this paper presents a methodology to quantitatively evaluate the potential energy savings and CO_2 emissions reduction of energy efficiency and low carbon policies in the residential and commercial buildings, industry and transport sectors. This paper is a prospective analysis of policy-specific energy savings and emissions reductions through 2030, and includes both key existing policies that will continue to be in effect and new policies likely to be implemented in the near-term.

2. Modeling Methodology

The China Energy End-Use Model[2] developed by LBNL was used to model macroeconomic and sectoral drivers of China's future energy demand and serves as the basis for scenario analysis of transport and industrial policy impacts. This model uses an accounting framework built using the Long-range Energy Alternatives Planning System (LEAP) software platform and consists of both energy consumption and production sectors, including: residential buildings, commercial buildings, industry, transportation, agriculture, and transformation (e.g. power generation, petroleum refining). The model addresses end-use energy demand characteristics including sectoral patterns of energy consumption, change in subsectoral industrial output, trends in saturation and usage of energy-using equipment, technological change including efficiency improvements, and links between economic growth and energy demand. Because this model is an end-use, technology-specific model, it cannot

[1] More details on the specific assumptions of the two efficiency scenarios can be found in Zhou et al. 2012.

[2] Detailed descriptions of all modeling parameters in the China Energy End-Use Model cannot be included in this paper due to limited space and scope. Documentation of the model's drivers, methodology and underlying assumptions can be found in Zhou et al. 2012.

easily evaluate systematic impact of building policies such as building codes and a complementary Excel spreadsheet model with building simulations was used to evaluate building sector policies.

2.1. Macroeconomic Drivers

For all scenarios and sectors including the building sector, macroeconomic parameters such as economic growth, population, and urbanization are assumed to be the same and are consistent with those in the China End-Use Model. International experiences and China's recent experiences with economic development highlight the important linkages between industrialization and rising energy demand, particularly in the industrial and transport sectors. To account for economic growth in China's near future, different rates of GDP growth were assumed for the periods between 2010 and 2030. Fast GDP growth on the order of 7.7% per year is expected to continue for the next decade, but will gradually slow to 5.9% by 2020 as the Chinese economy matures and shifts away from industrialization. Besides economic growth, another key driver in our bottom-up modelling methodology and scenario analysis is the urbanization rate and growth of the urban population. China as a developing country has and will continue to undergo changes in its physical built environment as a result of rapid urbanization. Over 290 million new urban residents were added from 1990 to 2007, and 380 million new urban residents are expected with 70% urbanization by 2030. The addition of new mega-cities and second-tier cities will drive commercial and residential demand for energy services and infrastructure development, as well as spur inter- and intra-city passenger transport activity.

2.2. Building Policy Evaluation Methodology

The building policy evaluation focuses on looking forward to ways of achieving as yet uncaptured savings, building on previous work that retrospectively evaluated the impact of building efficiency policies undertaken during the 11th FYP from 2006 to 2010 (Price et al. 2011). For the building sector, impacts analysis focused on heating, cooling and lighting and the policies evaluated are assume to reduce energy intensity without sacrificing comfort levels. While appliance policies such as equipment standards and labeling programs are expected to have important energy and emissions reduction potential in the buildings sector, they are not covered in this paper because their impacts have already been evaluated in previous studies such as Zhou et al. 2011.

2.2.1. Key Assumptions and Drivers

For the residential building sector, urbanization and growth in household incomes drive energy consumption as urban households generally consume more commercial energy than rural households and rising household incomes correspond to increases in size of housing units (and thus heating, cooling and lighting loads) and appliance ownership. Similarly, commercial building energy demand is driven by two key factors: building area (floor space) and end use intensities such as heating, cooling and lighting (MJ per m^2). In the China Energy End-Use model, commercial floor space is determined by the total number of service sector employees and the built space per employee as commercial building construction in China is expected to be driven by the expansion of the services sector, as was the case for today's developed economies. The potential for growth is not unlimited, however, as the Chinese population is expected to peak by about 2030 with the number of employees likely to peak closer to 2015 given the aging population. By comparing Chinese GDP per capita to that of other countries, we estimate that the percentage of workers in the tertiary sector will reach 52% by 2030. Floor space per employee has some room to grow: we forecast an increase of about 25% by 2030.

2.2.2. Policy Scenarios

Accelerated Building Codes (*Residential and Commercial*): Building codes affect new building heating and air conditioning loads by increasing the requirement of insulation of the building shell and HVAC system efficiency. The policy considered is an acceleration of the update of building codes in China, towards alignment with levels defined by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), and subsequent updating of those codes through 2030.

District Heat Metering and Controls (*Residential*): Historically, district heat feeding residential buildings in China were not metered or controllable by residences, leading to significant heat waste. Controls and metering are standard on new buildings. This policy constitutes the retrofit of existing buildings to allow for reduction of heating by residents. This policy does not affect commercial buildings, which are generally fitted with heating controls and metering by default.

District Heating Efficiency Improvement (*Residential and Commercial*): This policy is defined by increased penetration of high efficiency district heating generation and distribution. Improvements considered are (1) increased plant efficiency (2) reduction of thermal losses in pipelines and (3) increased pumping station efficiency.

Energy Efficiency Labels (*Residential and Commercial*): This policy assumes increased construction of 5-star buildings as defined by the Ministry of Housing, Urban-Rural Development's Building Energy Efficiency (BEE) labelling program. The BEE label evaluates buildings on a scale of one (least efficient) to five stars (most efficient) in terms of energy efficiency, with a focus on HVAC system efficiency, compulsory standard compliance, and optional building efficiency measures.

Retrofits – (*Commercial*): This policy assumes an increased number of commercial building retrofits. Retrofit measures include improved building envelope, controls, and heating systems (boilers) in commercial buildings. Commercial buildings usually have larger internal heat load intensity (from lighting, equipments, occupants) compared with residential buildings and therefore the heating retrofit may not be that effective compared with a residential building.

2.2.3. Modelling Parameters

Each policy is modelled as affecting a certain number of buildings and lowering the energy consumption of heating or cooling by a certain percentage.

- Buildings policies are assumed to impact urban buildings only.
- Building policies affect either the entire stock of buildings (i.e. retrofits) or new construction only (codes and labels)

Generally, for each building affected, each policy type improves the efficiency of either heating or cooling by the *unit improvement* $\phi^i(y)$, where *i* denotes either heating or cooling. Unit improvement can vary over year *y*, as in the case of building codes, which are updated periodically. The percentage of buildings effected, or *penetration rate* is denoted $\psi(y)$.

In the case that a given policy affects both existing and new buildings, energy savings is given by:

$$E^{i}_{Policy}(y) = E^{i}_{BAU}(y) \times \phi^{i}(y) \times \psi(y)$$

For policies that affect only new buildings, unit improvement and penetration rates apply to new construction only. The effect of these policies on the total building stock is therefore given by:

$$E^{i}_{Policy}(y) = E^{i}_{BAU}(y) \times \sum_{y'=2015}^{y} \phi^{i}(y') \times \psi(y') \times construction(y')/\ stock(y')$$

The modelling parameters for each building policy evaluation are shown in Table 1 below.

Table 1: Summary of Building Policy Modelling Parameters

Policy	Sector	Variable	Scope	Modeling Parameter	2015	2020	2025	2030
Accelerated Building Codes	Res.	$\phi(y)^{heating}$	New Buildings	45% heating energy and 18% cooling energy reduction compared to current buildings code by 2030. Based on simulation.	15%	28%	37%	45%
		$\phi(y)^{cooling}$			6%	11%	15%	18%
		$\psi(y)$		All new buildings affected	100%	100%	100%	100%
	Com.	$\phi(y)^{heating}$	New Buildings	50% heating energy and 40% cooling energy reduction compared to current buildings code by 2030. Based on simulation.	32%	42%	46%	50%
		$\phi(y)^{cooling}$			22%	32%	32%	40%
		$\psi(y)$		All new buildings affected.	100%	100%	100%	100%
District Heating Metering and Controls	Res.	$\phi(y)^{heating}$	Existing Buildings	Setpoint reduced from 22-25C to 18C. Heating off when unoccupied. Based on simulation.	40%	40%	40%	40%
		$\psi(y)$		Half of currently unmetered buildings retrofit by 2030.	0%	16%	32%	50%
District Heating Efficiency Improvement	Res.	$\phi(y)^{heating}$	All Buildings	Single-tier improvement 80% to 91% efficiency. Two-tier improvement 60% to 81% efficiency. 5% pump system efficiency improvement.	21%	21%	21%	21%
		$\psi(y)$		Retrofit of 80 million m2 per year starting 2015.	1%	6%	11%	16%
Energy Efficiency Labels	Res.	$\phi(y)^{heating}$	New Buildings	Definitions of 5 Star include 70% heating and 80% cooling improvement relative to 1980 buildings.	70%	70%	70%	70%
		$\phi(y)^{cooling}$			80%	80%	80%	80%
		$\psi(y)$		10% of new buildings in 2015 increasing to 25% in 2030.	10%	15%	20%	25%
	Com.	$\phi(y)^{heating}$		Definitions of 5 Star include 70% heating and 80% cooling improvement relative to 1980 buildings.	70%	70%	70%	70%
		$\phi(y)^{cooling}$			80%	80%	80%	80%
		$\psi(y)$		10% of new buildings in 2015 increasing to 25% in 2030.	10%	15%	20%	25%
Retrofits	Res.	$\phi(y)^{heating}$	Existing Buildings	25% heating energy and 10% cooling energy reduction compared to 1980 codes. Based on simulation.	25%	25%	25%	25%
		$\phi(y)^{cooling}$			10%	10%	10%	10%
		$\psi(y)$		Goal of 400 million m2 per year (FYP 13 goal).	1%	4%	6%	6%
Retrofits	Com.	$\phi(y)^{heating}$	All Buildings	20% heating energy and 10% cooling energy reduction compared to 1980 codes. Based on simulation.	20%	20%	20%	20%
		$\phi(y)^{cooling}$			10%	10%	10%	10%
		$\psi(y)$		Retrofit of all pre-2000 buildings by 2030.	0.4%	2%	4%	5%

2.3. Industrial Policy Evaluation Methodology

While the industrial share of energy demand will likely decrease with continued economic development and structural change, the industrial sector will continue to have important implications for China's energy and carbon pathways. Seven of the largest energy-consuming industries are singled out for in-depth analysis and modelled in the China Energy End-Use Model, including cement, iron and steel, aluminum, paper, glass, ammonia and ethylene in addition to an "other industry" subsector to capture other industries such as the various manufacturing and processing industries.

2.3.1. Key Assumptions and Drivers

For the industrial sector, analysis was conducted for seven energy-intensive industrial sub-sectors based on physical drivers for each industrial product and recent and expected efficiency and technological trends. For cement, steel and aluminum production, for example, the scenarios were based on major physical driver relationships to built environment requirements for growing urban population, with floor space construction area as a proxy. Ammonia production, in contrast, was modelled as a function of sown area and fertilizer intensity while ethylene production was based on population and per capita demand for plastics. For each sub-sector, we developed projections of process efficiency requirements and technology shift for materials production and examined energy return on energy investment for primary energy producing sectors.

2.3.2. Policy Scenarios

Efficiency Improvements (All Sectors): Recent policies to promote industrial efficiency improvements in China have included the Ten Key Projects, the Top 1000 Energy-Consuming Enterprises Program, and the closure and phase-out of small and outdated industrial production capacity. The impacts of these policies as reported and retrospectively evaluated in Price et al. 2011 serves as the basis for efficiency improvement parameters used in the alternative policy scenario. Policy impact is modelled using a counterfactual baseline scenario that assumes no efficiency improvements (i.e., frozen energy intensity of production) in the seven modelled industries after 2010. An alternative scenario was developed in which all seven key industries meet their stated targets and reach the current world best practice energy intensity ~2030 as a result of effective efficiency policies and measures (See Fridley et al. 2011 for more details on Chinese energy intensity targets and basis for current world best practices).

Technology Switching (Cement, Iron and Steel and Aluminum Sectors): In addition to industrial efficiency improvements, recent policies in China have also focused on technology switching or upgrading from inefficient, older production processes and technologies to newer, more efficient processes and technologies. As a result of technological improvements associated with the technology switch, the average energy intensity per unit of industrial product is lowered. For each sector, a frozen technology share scenario with technology shares assumed to remain constant at 2010 levels through 2030 and a technology switching scenario with rising efficient (i.e., lower energy intensity) technology shares are adopted (Fridley et al. 2011).

Alternative Fuels for Cement Sector: A potential policy to reduce cement CO_2 and other pollutants emissions is to displace coal by increasing the use of alternative waste fuels in cement production. Three scenarios are used to model three possible paces of increasing the share of alternative fuel use based on China's alternative waste availability: a frozen scenario at the 2009 share; a reference scenario and an accelerated scenario.

2.3.3. Modelling Parameters

The modelling parameters for each industrial policy evaluation are shown in Table 2 below.

Table 2: Summary of Industrial Policy Evaluation Modelling Parameters

Policy	Sector	Modeling Parameter	2010	2030
Efficiency Improvement	Iron and Steel	Final Energy Intensity of Production (tons of coal equivalent per million metric ton of product)	0.57	0.5
	Cement		0.11	0.09
	Aluminum		3.98	2.69
	Paper		0.73	0.55
	Ammonia		1.61	1.4
	Ethylene		0.65	0.56
	Flat Glass		0.34	0.3
Technology Switching	Cement	Share of Rotary Kilns	79%	100%
		Share of Shaft Kilns	21%	0%
	Iron and Steel	Basic Oxygen Furnace Share	87%	81%
		Electric Arc Furnace Share	13%	19%
	Aluminum	Primary Production	75%	64%
		Secondary Production	25%	36%
Cement Alternative Fuel	Cement			
Frozen Scenario		Alternative Fuel Share	5.3%	5.3%
Reference Scenario		Alternative Fuel Share	5.3%	26%
Accelerated Scenario		Alternative Fuel Share	5.3%	41%

Note: 1 ton of coal equivalent (tce) is the standard Chinese unit for energy and is equal to 29.27 GJ.

2.4. Transport Policy Evaluation Methodology

As China continues to urbanize with rising household income, the transport sector is expected to contribute to a growing share of national energy consumption and CO_2 emissions. The impact of both private and public transport policies are evaluated through scenario analysis using the China Energy End-Use Model.

2.4.1. Key Assumptions and Drivers

Transport sector activity is driven by demand for freight transport and for passenger transport. Freight transport is calculated as a function of economic activity measured by value-added GDP while passenger transport is based on average vehicle-kilometers traveled by mode (e.g., bus, train, car) of moving people. For passenger transport, growing vehicle-kilometers traveled in different modes is driven by population growth and growing demand for personal transport with rising income levels. The largest mode of passenger transport is in road transport, which is driven primarily by the burgeoning ownership of private cars that follows rising per capita income. By 2030, personal car ownership reaches 0.33 per household, which while extremely high compared to current values, is still considerably below current levels in the United States and Europe.

2.4.2. Policy Scenarios

<u>Fuel Economy Standards:</u> China introduced its first national standard on vehicle efficiency in 2004, with the third phase of the standard to be implemented by 2015. A frozen scenario with fuel efficiency maintained at current level through 2030 and a policy scenario with continually rising fuel efficiency are adopted.

Electrification and Deployment of Electric Cars: Market entry of electric cars have been promoted by the government through financial subsidy programs for consumers and manufacturers as well as demonstration programs in the last few years. Three scenarios reflecting different paces of vehicle electrification transport are used: a counterfactual scenario in which electric cars fail to saturate the market, a base policy scenario representing continuation of recent policies and pace of electrification and an accelerated policy scenario with faster electrification due to stronger policy push.

Hybrid Cars: Although hybrid vehicle development was previously supported by government research and development programs, policy support has declined as the domestic manufacturing technology is now considered commercialized and profitable with the domestic hybrid market expected to outpace that of electric cars. Two scenarios are used to to evaluate the potential impact of hybrid cars: a counterfactual scenario where hybrid technology is not further deployed and a baseline scenario with continued growing penetration of hybrids.

Bus Rapid Transit (BRT): China has 13 BRT systems with total length of 430 kilometers and plans for new and expanded systems in the near future. BRTs impact energy and CO_2 emissions by inducing transport mode shifting, raising both bus and overall fuel efficiency from increases in average traffic speed, reduce vehicle kilometers travelled and decrease automobile usage and ownership rates. A simplified model using Chinese BRT ridership survey data and four scenarios was developed. The four scenarios include two sets of reference and accelerated scenarios of modal shift, with each set having a base and acceelerated pace of BRT bus fleet growth.

Car-Trip Diversion: Policies to divert travel away from personal cars to other forms of transportation or transportation at a different time – such as vehicle ownership restrictions, congestion pricing and expansion of mass transit - reduce urban congestion and its related environmnental and economic problems. To test the impact of various policies designed to divert travel from cars to other forms, two scenarios are used in which the annual travel from the equivalent of 10 million cars with 9000 km average annual vehicle-kilometers-travelled by 2030 are redistributed to all modes and other motorized modes only.

2.4.3. Modelling Parameters

The modelling parameters for each policy evaluation are shown in Table 3. The modelling parameters for the car-trip diversion policies cannot be summarized using simple variables due to the need to calculate the vehicle-kilometers travelled separately for each diverted mode due to different average loads and vehicle-kilometers travelled per trip. More details on the calculations used in modelling the car-trip diversion policy scenarios will be provided in a forthcoming report (Zhou et al. 2013).

Table 3: Summary of Transport Policy Evaluation Modelling Parameters

Policy	Scope	Modeling Parameter	2010	2030
Fuel Economy Standards	Conventional personal gasoline, diesel and hybrid cars	Average fleet efficiency, in liters per 100 kilometers	7.7	4.3
Electric Cars Deployment	Passenger car market	Electric car share		
No Electric Cars Scenario			0%	0%
Base Policy Scenario			0%	10%
Accelerated Policy Scenario			0%	25%
Hybrid Cars	Passenger car market	Hybrid car share	0%	20%
		Hybrid car energy intensity relative to standard gasoline car	80%	50%

Bus Rapid Transit (BRT) Fleet Expansion				
Base Policy Scenario 1	BRT fleet	Number of BRT Buses	1125	4500
		Total Mode Shift to BRT	0%	16%
Base Policy Scenario 2		Number of BRT Buses	1125	11250
		Total Mode Shift to BRT	0%	16%
Accelerated Policy Scenario 1		Number of BRT Buses	1125	4500
		Total Mode Shift to BRT	0%	32%
Accelerated Policy Scenario 2		Number of BRT Buses	1125	4500
		Total Mode Shift to BRT	0%	32%

3. Policy Impact Results and Discussion

3.1. Buildings Policies

Since the effects of each policy on building energy demand are significant, it is important to carefully track the interactions and overlap between policies. In general, the impacts of each policy are lower when implemented in combination to another policy, since they act on an improved baseline. In order to quantify these interactions, we consider four policy combinations:

Each Policy Individually – This combination does not take interactions between policies into account.

All Policies Together – This combination takes into account all interactions between policies.
New Buildings Only – Policies that affect new construction only – Building Codes and Energy Efficiency Labels

Existing Buildings Only – Policies that affect existing buildings – District Heating Reform and Commercial Building Retrofits.

Accounting for the interaction between policies is straightforward. For example, if the efficiency improvement to heating from accelerated building codes is

$$\phi(y)^{heating}_{Codes}$$

And the efficiency improvement to heating from District Heating Metering and Controls is

$$\phi(y)^{heating}_{Metering}$$

then the savings from both policies applied is given by

$$E^{i}_{Policy}(y) = E^{i}_{BAU}(y) \times \psi(y) \times \left(1 - \phi(y)^{heating}_{Codes}\right) \times \left(1 - \phi(y)^{heating}_{Metering}\right)$$

The final and primary energy savings results are given in Table 4.

Table 4: Potential Energy Impacts of Building Policies – Final and Primary Energy

	Final Energy			Primary Energy		
Policy	**2010**	**2030**	**Cumulative**	**2010**	**2030**	***Cumulative***
Residential						
Demand (Mtce)						
Heating	92.1	150.6		120.0	185.1	
Cooling	9.1	16.2		26.3	35.6	
All HVAC	101.2	166.7		146.3	220.7	
Savings (Mtce)						

Building Codes		23.2	201.1		29.5	263.7
Heating Reform - Controls		11.8	95.6		12.3	103.8
Heating Reform - Plant & Transmission Efficiency		0.0	0.0		2.1	19.0
Energy Efficiency Labels		8.1	67.3		10.9	93.4
Retrofits		2.5	26.0		3.2	34.2
Total Individual		**45.6**	**390.0**		**58.0**	**513.9**
All Policies		**41.6**	**364.3**		**52.5**	**478.0**
Existing Buildings		**14.0**	**119.1**		**16.7**	**150.1**
New Buildings		**30.1**	**260.7**		**38.8**	**346.1**
Commercial						
Demand (Mtce)						
Heating	66.4	95.0		75.3	103.0	
Cooling	12.5	29.6		35.1	62.0	
All HVAC	78.9	124.5		110.4	165.0	
Savings (Mtce)						
Building Codes		28.7	249.9		37.1	339.4
Energy Efficiency Labels		9.4	72.6		12.6	100.5
Heating Reform - Plant & Transmission Efficiency		0.0	0.0		1.0	7.8
Retrofits		1.7	12.4		2.6	18.9
Total Individual		**39.8**	**334.9**		**53.4**	**466.6**
All Policies		**37.1**	**319.4**		**49.5**	**443.4**
Existing Buildings		**1.7**	**12.4**		**3.6**	**26.6**
New Buildings		**35.9**	**309.7**		**46.9**	**422.6**
Total						
Heating	158.5	245.5		195.2	288.0	
Cooling	21.6	45.7		61.5	97.6	
All HVAC	180.1	291.2		256.7	385.6	
Savings (Mtce)						
Building Codes		51.9	451.0		66.6	603.1
Energy Efficiency Labels		21.1	168.2		25.0	204.3
Heating Reform - Plant & Transmission Efficiency		0.0	0.0		3.0	26.7
Retrofits		9.9	79.7		13.6	112.3
Total Individual		**42.3**	**360.9**		**56.5**	**500.8**
All Policies		**82.7**	**709.4**		**107.5**	**957.3**
Existing Buildings		**43.3**	**376.8**		**56.1**	**504.7**
New Buildings		**49.9**	**428.9**		**63.6**	**572.7**

Note: 1 Mtce = 1 million metric tons of coal equivalent = 29.27 million GJ.

These results suggest that building codes are the most impactful policy considered for both building types, accounting for over half of all savings. The next more impactful policies are heating reform from metering and controls in residential buildings and retrofits in commercial buildings. Each of these policies could save around 100 Mtce (2.93 EJ). In comparing the residential and commercial building sectors, similar magnitudes of savings are achieved. There is also moderate overlap between policies, with savings from all combined policies together accounting for 12% less than the sum of individual policies. Most of the savings (73%) can be achieved by policies that affect new buildings.

3.2. Industrial Policies

3.2.1. Efficiency Improvement

The energy efficiency of China's industry increased overall since 2005 with both economic and physical energy intensities of major industrial products decreasing during China's 11th FYP period (Ke et al., 2012). This trend is expected to continue under the continuous efficiency scenario as industrial subsectors continue to improve efficiency with annual average reductions of between 0.6% to 1.6% in energy intensity per unit of industrial product through 2030. As a result, total primary energy use under the continuous efficiency scenario increases by very little from 2139 Mtce in 2010 to 2466 Mtce in 2030. In contrast, primary energy use grows rapidly under the frozen efficiency scenario from 2250 Mtce to 3868 Mtce during the same period. This shows that relative to the frozen efficiency scenario, continuous efficiency improvements can result in annual energy savings of 1400 Mtce by 2030, or cumulative savings of 14,790 Mtce over the twenty year period. Most of this savings will be from the other industry subsector, followed by savings in the iron and steel, aluminum and paper sectors.

In terms of CO_2 emissions reduction, the vast majority of the reduction will come from lowered coal demand, which decreases by as much as 40% or over 1100 Mtce annually by 2030. As a result, an annual reduction of 3100 Mt CO_2 emissions is achieved from coal savings of improved industrial efficiency by 2030. Combined with petroleum and natural gas energy savings that result in further reductions of 520 Mt CO_2 emissions in 2030, industrial efficiency improvements across the seven major industries and other industry could achieve total annual reduction of 3620 Mt CO_2 emissions by 2030. From 2010 to 2030, this sums up to cumulative CO_2 emission reductions of over 38 billion tons of CO_2.

3.2.2. Technology Switching

Because China's cement industry is already relatively efficient with rotary kilns having a majority share of kiln technology, there is small incremental savings (~1-8 Mtce per year) from a complete phase-out of inefficient vertical shaft kilns. In 2030, the total annual energy savings of 7.9 Mtce is possible with cumulative savings of 102 Mtce from 2010 to 2030. Most of this savings will be in the form of coal, resulting in possible reductions of 21 Mt CO_2 emissions per year in 2030 and cumulative reduction of 273 Mt CO_2 through 2030.

Similar to the cement industry, the iron and steel industry also has small incremental primary energy savings as the more efficient electric arc furnace has a 6% greater share in 2030 with technology switching. This translates into annual primary energy savings of 27 Mtce in 2030 and cumulative savings of 317 Mtce from 2010 to 2030, with coal as the dominant form of energy savings. As a result of technology switching to the more efficient EAF production, the annual iron and steel CO_2 emissions reduction are on the scale of 80 Mt by 2030 with cumulative total reduction of 921 Mt CO_2 from 2010 through 2030 (Figure 1).

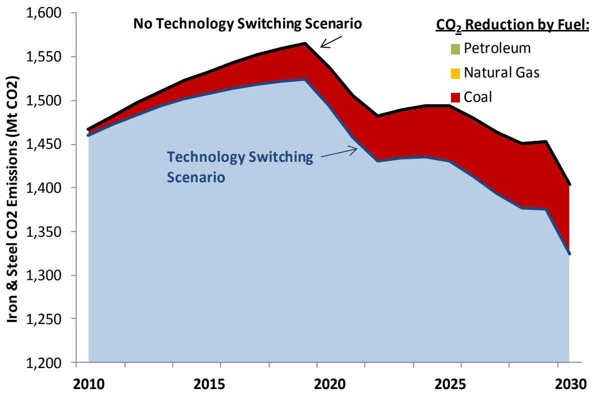

Figure 1: Iron and Steel CO2 Emissions under Technology Switching Scenarios and Reduction Potential by Fuel

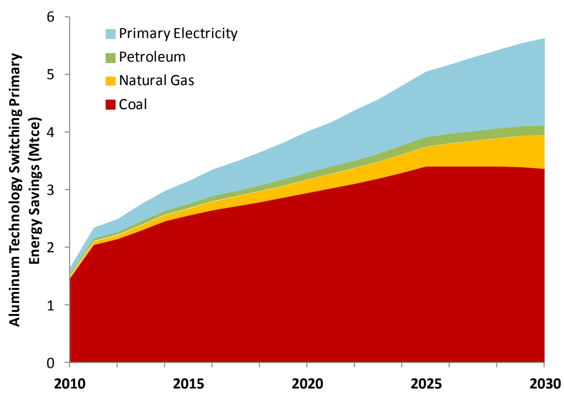

Figure 2: Energy Savings from Aluminum Technology Switching

Increasing the share of more efficient secondary production of aluminum through more aggressive production technology switching can result in growing energy savings when compared to the frozen technology shares scenario without technology switching, as seen in Figure 2. The growth in primary energy savings over time is evident with annual savings growing from 2.5 Mtce in 2012 to 5.6 Mtce in 2030. Cumulatively, primary energy savings from aluminum technology switching could total 84 Mtce from 2010 to 2030. In parallel with the primary energy savings by fuel, most of the CO_2 emissions reduction is in the form of coal savings, with a smaller share from natural gas savings. From 2010 to 2030, 182 Mt CO_2 emissions could be reduced as a result of the technology switch to secondary aluminum production.

3.2.3. Alternative Fuels for Cement Production

The use of alternative fuels in cement production as a substitute fuel for coal help reduce coal inputs to the cement sector, resulting in lowered cement coal consumption due to the coal offset by alternative fuels (Figure 3). Compared to the frozen alternative fuel scenario, the growing share of alternative fuels to 26% by 2030 under the reference alternative fuel scenario can offset 20.6 Mtce of coal per year in 2030, or reduce total coal use in the cement sector by 21%. Under the accelerated alternative fuel scenario, the potential coal offset would increase to 36 Mtce annually in 2030, or the equivalent of 36% reduction in total cement coal use in the frozen scenario. From 2010 to 2030, cumulative coal offsets from reference and accelerated paces of alternative fuel use in the cement sector would total 268 Mtce and 512 Mtce, respectively.

Moreover, since alternative fuels have a lower CO_2 emission factor than coal, net CO_2 emission reductions also result from greater use of alternative fuels in the cement sector (Figure 4). Specifically, annual CO_2 emissions would be 15 and 21 Mt CO_2 lower under the reference and accelerated alternative fuels scenario, respectively, in 2030 when compared to the frozen alternative fuel scenario. This translates into 8% and 11% lower annual total CO_2 emissions in 2030, and cumulative reductions of 220 and 322 Mt CO_2 emissions from 2010 to 2030 under the reference and accelerated alternative fuel scenarios.

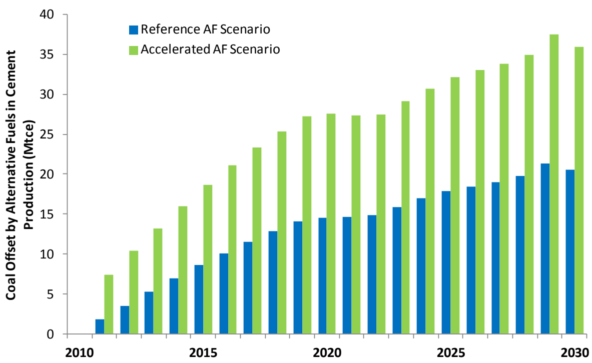

Figure 3: Cement Production Coal Offset by Alternative Fuels

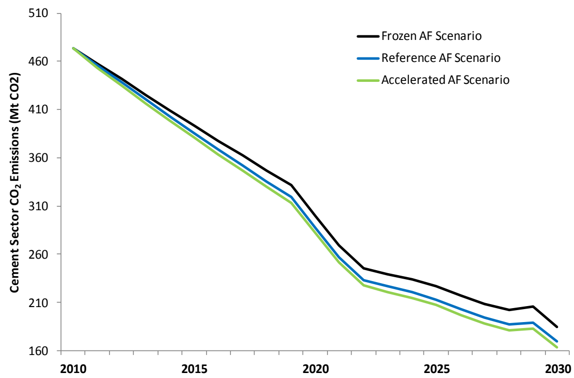

Figure 4: Cement CO_2 emissions by Alternative Fuel Scenario

In sum, different industrial policies will have varying impacts on energy savings and emission reductions. Some policies, such as technology switching in the cement and iron and steel sectors, will have relatively small incremental impact due to the significant policy efforts already undertaken and savings already achieved. Continued efficiency improvements across the seven heavy industries, however, will have significant energy savings and emissions reduction impacts due to the sheer magnitude and scale of China's industrial production.

3.3. Transport Policies

3.3.1. Fuel Economy Standards

In the absence of further strengthened fuel economy standards, China's total fuel consumption from its expanding car fleet would soar over 300% to a total of nearly 140 Mtce by 2030. By 2030, savings from continued improvement in fuel economy standards would reach nearly 60 Mtce, for a cumulative total of 560 Mtce of savings over the period. The savings in 2030 alone would be nearly twice the total amount of fuel consumption by personal vehicles in 2008, when the latest standards went into effect. Emissions savings are substantial, reaching 131 Mt of CO_2 in 2030, with a cumulative total of 1.2 billion t CO_2 over the period to 2030

3.3.2. Electric Cars Deployment

As a result of electric cars replacing more and more of the gasoline cars and some hybrid cars over time, electricity demand from the passenger road transport sector will increase along with decline in gasoline demand. Compared to the no electric car policy scenario, electricity demand for new electric cars will grow rapidly after 2020, from 9 TWh to 27 TWh in 2030 under the base EV policy scenario. If the market saturation of electric cars is accelerated by more aggressive electrification policies, then electric cars' demand for electricity will more than double from the base scenario to 67 TWh in 2030 as seen in Table**Error! Reference source not found.** 5. At the same time, gasoline demand will be lowered by electrification as more gasoline cars are displaced by electric cars. Figure 6 shows resulting in total reductions of 7 and 17 Mtoe for the base and accelerated electric car deployment policy scenarios, respectively. From 2010 to 2030, cumulative gasoline reduction could amount to 53 Mtoe and 125 Mtoe for the two policies.

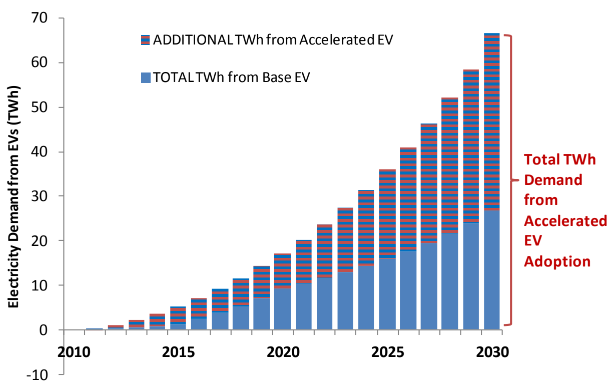

Figure 5: Electricity Demand Increase from Electric Car Deployment Fuel Switching by Scenario

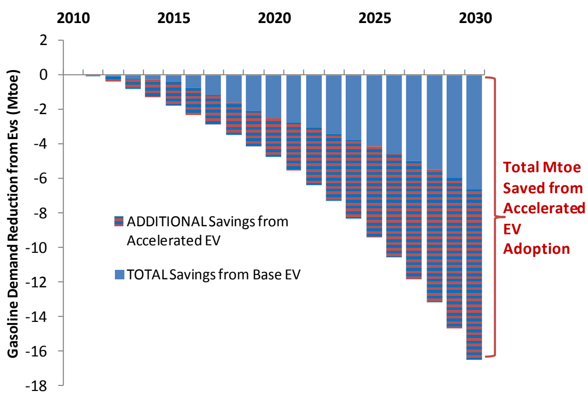

Figure 6: Gasoline Reduction from Electric Car Deployment Fuel Switching by Scenario

The net CO_2 effects of increased electricity use and reduced gasoline consumption depends substantially on the fuel mix of the power sector. Assuming China is successful in promoting renewable generation and its power sector continues to decarbonize with continual shift away from fossil fuels towards nuclear and renewables, road transport electrification will have a net reduction effect on CO_2 emissions from cars. Although rising electricity demand may offset gasoline reduction in terms of net energy, the carbon intensiveness of electricity declines over time and thus emits less carbon than gasoline, assuming the IPCC emission factor of 18.9 tC/TJ of gasoline. This is particularly true in the later years when the power sector becomes more decarbonized with greater generation from non-fossil fuels, as the CO_2 emission savings from electric cars deployment grow from under 2 Mt annually before 2020 to nearly 8 Mt annually by 2030 under the base policy scenario. Under the accelerated policy scenario, annual reduction reaches 5 Mt CO_2 by 2020 and rises to 21 Mt CO_2 in 2030 with cumulative reduction of 142 Mt CO_2 over the 20 year period.

3.3.3. Hybrid Cars

The growing fleet of hybrid cars begins to significantly impact the growth of fuel consumption by passenger cars in the 2020s when China achieves full hybrid efficiency potential, as seen in Table 5 below.

Table 5: Energy and CO_2 Savings from Hybrid Penetration

	2015	2020	2030	Cumulative
Energy (Mtce)	0.5	2.8	9.4	69.0
CO_2 (Mt)	1.1	6.2	21.0	153.6

In 2030, passenger car fuel consumption is expected to reach 77 Mtce, compared to 86.5 Mtce in the case where hybrids are not introduced. Savings from hybrid penetration reach 9.4 Mtce in 2030, or a cumulative 69 Mtce. CO_2 savings rise commensurate from 1.1 Mt in 2015 to 21 Mt in 2030, for a cumulative total of 153.6 Mt.

Hybrid cars are an important technology today for increasing fuel economy of passenger cars. Although China has not yet reached the technical capabilities of some international companies in hybrid production, it remains a key focus of its automotive development plans and full hybrid capability is expected to be achieved by 2020. Further, because hybrid technology is fully commercialized, it can be deployed more quickly and extensively than EVs, for which numerous challenges remain to full commercialization.

As an efficiency measure, however, the overall savings from the introduction and deployment of hybrid technology is dramatically lower than those achievable from continued improvement in mandatory minimum fuel economy standards for all vehicles, despite the high unit savings of hybrids. Compared to the 9.5 Mtce savings in 2030 from hybrids, total savings from fuel economy standards is expected to be over six times greater, at 60 Mtce in 2030 (these savings are in addition to the savings from hybrids). This contribution could be significantly higher if technology development policy were directed towards full hybridization of the gasoline-powered car fleet in the future, although this would likely first require full domestication of hybrid technology and would be unlikely to be realized by 2030.

3.3.4. Bus Rapid Transit Fleet Expansion

The energy savings and emissions impact of different scale and pace of BRT expansion are shown in Table 6. These results do not include offsets to savings from the induced travel that BRT systems can engender: this was found to be 1.9% of trips on the Xiamen BRT system (Cui et al. 2010). In the baseline case of flat mode shift shares and a quadrupling of the system size by 2030, savings in 2030 reached 59 ktce, with cumulative savings of 845 ktce. At the other extreme, an accelerated shift to BRT from motorized modes and a 10-times expansion of the system by 2030 resulted in 297 ktce of savings in 2030, with cumulative savings reaching 3,609 ktce.

Except for Chongqing where BRT buses run on compressed natural gas (CNG), and Guangzhou, where buses operate on LPG, buses in the other systems run on diesel fuel. For the most part, the fuel of avoided modes (cars, taxis, motorcycles) is gasoline, which is less carbon intensive than diesel. Nonetheless, CO_2 reductions are considerable, ranging from 1.8 million tonnes of cumulative savings in the baseline case to 7.6 million tonnes in the accelerated expansion case.

Table 6: BRT Energy and Emissions Savings to 2030

	Energy (ktce)				CO_2 (kt)			
Scenario	*2015*	*2020*	*2030*	*Cumul.*	*2015*	*2020*	*2030*	*Cumul.*
BRT Accelerated Scenario 2	111.9	182.1	297.0	3,609	238	385	622	7,606
BRT Accelerated Scenario 1	60.2	82.8	118.8	1,628	128	175	249	3,433
BRT Baseline Scenario 2	55.9	91.0	148.6	1,846	118	190	308	3,855
BRT Baseline Scenario 1	30.1	41.4	59.4	845	63	87	123	1,767

For China's densely populated cities, BRT systems provide a number of benefits, including reduced road congestion, improved travel times, increased transit reliability, reduced transit switching, and a convenient alternative to other modes of transportation. To the extent that BRT induces trip-mode shifting away from other motorized modes such as cars or taxis, the system can contribute to energy savings as well.

Although only Guangzhou and Xiamen have analyzed the energy impact of their BRT systems, the results so far suggest that energy savings are fairly modest compared to other transport-related policies. A simple calculation of induced savings per bus shows that each BRT bus results in about 26 tce of annual energy savings though reduction in other motorized transport modes. For BRT to achieve the same scale of savings as fuel efficiency standards (though scalability is an issue), over 2.2 million BRT buses would need to be deployed by 2030, or over 350,000 buses to match the savings of hybrid cars, compared to around 1200 today.

3.3.5. Car-Trip Diversion

In the baseline scenario, total fuel consumption of all motorized passenger modes reaches 356 Mtce by 2030 (about 5.8 million barrels per day). Under a set of policies that results in the diversion of travel equal to 10 million cars by 2030 distributed among other motorized modes, total fuel consumption drops to 351 Mtce, or to 350.6 Mtce if distributed among other motorized and non-motorized modes. It

is clear that the savings accrue primarily from trip diversion itself and is less sensitive to the mix of alternative modes that account for the diverted trips.
Total fuel savings in the case in which trip diversion is redistributed to all alternative modes reach nearly 5 Mtce by 2030, for a cumulative total of 59 Mtce. Where trip diversion is accommodated only by alternative motorized modes, savings in 2030 fall to 4.5 Mtce, for a cumulative total of 54 Mtce (Table 7).

Table 7: Energy and Emissions Savings from Diverting Travel of 10 Million Cars

	Energy (Mtce)				**CO_2 (Mt)**			
Scenario	*2015*	*2020*	*2030*	*Cumul.*	*2015*	*2020*	*2030*	*Cumul.*
Diverted car trips to all modes	1.6	3.0	4.9	58.9	3.6	6.6	10.6	127.9
Diverted car trips to other motorized modes	1.5	2.8	4.5	54.0	3.3	6.1	9.6	117.3

As with the case with BRT, policies that induce reduction in car travel are often primarily implemented to relieve congestion and associated problems, such as a growing concentration of pollution from car tailpipe emissions. Restriction on ownership, congestion pricing, and expansion of mass transit options all contribute to offsetting these various problems. Moreover, to the extent that car travel is replaced by other modes of travel, such as walking, biking, or mass transit, such policies can also save energy.

In the scenario analyzed here, a simple calculation shows that in 2030, displacing one car's worth of annual travel by alternative modes saves, on average, a modest 0.5 tce per car per year. In contrast, the addition of a single BRT bus with its higher passenger load, on average, generated about 26 tce of savings. To achieve the magnitude of savings from increasing fuel economy standards for cars, over 120 million cars' worth of annual travel would need to be diverted, and it is questionable if alternative modes could be scalable to accommodate this magnitude of trip diversion given infrastructure limitations.

4. Conclusions

The continued rapid industrialization and urbanization of China present substantial challenges in constraining the concomitant growth in energy consumption and CO_2 emissions. Since 2005, China's government has actively been proposing and implementing a wide range of policies to increase efficiency though technology turnover, mandatory retirements, retrofit programs, and expansion of mandatory efficiency standards, among others, However, as seen in Price 2011, it is difficult to assess the actual contribution of these policies owing to varying approaches to calculating savings, vague boundary issues, double-counting, and uneven reporting. By using a standard bottoms-up approach to policy impact evaluation, this study has been able to assess the relative future contributions of a wide range of existing and potential new policies across the building, industry, and transportation sectors, providing insight into the scale of potential further savings possible in the future and input into policy prioritization.

In the building sector, building codes rank as the most powerful tool for saving energy in residential and commercial buildings, reaching about 66 Mtce annually by 2030 for a reduction of over 100 Mt of CO_2 in that year. The scale of savings is consistent with the expected scale of new building construction over the next 17 years as urbanization continues unabated. The leading edge of new building efficiency is reflected in the savings possible from energy efficiency labelling of about 20 Mtce, while measures aimed at existing infrastructure—existing buildings and district heating schemes—return less in energy savings.

In the industrial sector, the focused effort since 2005 to improve heavy industrial efficiency through technology switching in cement, iron & steel and aluminum industries has reduced the scope of further savings, though about 40 Mtce of energy and 110 Mt CO_2 could be saved annually in 2030 though phase-out of the remaining vertical shaft kilns in the cement industry and expansion of secondary production processes in both the iron & steel and aluminum industries. The scope of technology shift in these latter two sectors, however, is limited by the amount of scrap steel and aluminum available for recycling. For cement, further savings can be gained by increasing the proportion of alternative fuels in the sector, which could lead to a further 10% reduction in CO_2 emissions in 2030 with a 36% reduction in coal use. Given the enormous scale of industrial production in China, however, great potential remains to increase efficiency across all sectors in aggregate, totalling 1400 Mtce and 3100 Mt CO_2 in 2030 across seven major industrial sectors.

In the transport sector, as in the building sector, the expected large increase in transportation stock in the future provides the greatest opportunity in savings from mandatory fuel economy standards, saving 60 Mtce and 131 Mt CO2 in 2030. Technology choices within the transportation stock have less impact. Deployment of electric vehicles offsets gasoline use, but actual emissions reductions depend on the pace of power sector decarbonization, which is expected to accelerate through the 2020s, and could provide up about 8 Mt of CO2 savings in the base case. Savings are also possible from proliferation of hybrid technology, which is already fully commercialized. In 2030, higher hybrid vehicle penetration could reduce emissions by about 21 Mt CO2. In urban areas, transportation efforts have also focused on limiting car ownership, introduction of improved mass transit, deployment of dedicated BRT lines, and consideration of congestion charges and other methods to reduce travel in cars. Savings in 2030 from such programs are fairly modest, reaching less than 1 Mt CO_2 reduction in the case of BRT to about 11 Mt CO_2 with the diversion of travel from 20 million vehicles. Nonetheless, these policies achieve other development goals, such as reduced congestion and tail-pipe emissions, and lowered need for road building.

A limitation of our modelling methodology is the simplifying modelling assumption that the policies evaluated will be fully implemented with 100% compliance, where as recent experiences have shown that significant implementation barriers including limited enforcement, reporting and evaluation capabilities and divergence between central and local government priorities for implementation still exist. Because this paper aimed to quantify the relative orders of magnitude of savings for policies within sectors and across sectors as the basis for guiding policy prioritization, uncertainties with policy impacts were not evaluated in this paper. We acknowledge that while implementation challenges and uncertainty with modelling parameters will affect the total possible energy savings and emissions reduction impact of the policies evaluated, the results of this paper is nevertheless helpful in providing some guidance on the relative magnitude of savings between the sectoral policies evaluated. For instance, the results of this study suggest that a variety of industrial and building efficiency policies will be key to capturing the large energy savings and emissions reduction potential in these sectors. Although transportation will consume an increasing proportion of China's energy use, continued emphasis on increasing the stringency of mandatory fuel economy standards could deliver the bulk of potential savings in this sector.

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